SEWAGE EFFLUENT TREATMENT

IN AN

ARTIFICIAL MARSHLAND

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Sewage Effluent Treatment in an Artificial Marshland

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ABSTRACT

Sewage lagoons are a common means of wastewater treatment for smaller Ontario communities. Frequently, the capacity of receiving waters to accept effluent from such facilities is limited by inadequate dilution during summer low flow periods leading to nuisance proliferation of plants and algae, with attendant widely fluctuating oxygen levels. Storage of effluent during periods of low flow requires large areas of land, and replacement of lagoons with mechanical treatment systems is very costly for small municipalities. Natural or artificial marshlands may provide a viable treatment alternative.

To determine the potential of wetlands for year-round sewage treatment in Ontario, an experimental study using an artificial marsh was established in 1979. The study is designed to define the degree of pretreatment required prior to waste discharge to wetlands, maximum loading rates, required retention periods and depths of liquid to establish optimal operational limits for these types of systems.

The artificial marsh has been constructed at the site of the Listowel sewage lagoon which consists of an aeration cell and two lagoons operated in series. The experimental marsh consists of five separate systems as well as a small control marsh for monitoring rates of evapotranspiration. Systems I, II and III receive effluent from the east lagoon, the first in series, while Systems IV and V receive aeration cell effluent. System I consists of a deep pond, a shallow marsh and a channelized marsh operated in series, Systems III and V are channelized marshes, and Systems II and IV are shallow marshes. The channelized and open marshes are planted with cattails, *Typha* spp.

Each system is capable of operating at flow rates of 0.5 to 2 times average design and at various depths and retention times. Flows are controlled and measured by V-notch and rectangular weirs and water level recorders. Routine parameters (i.e. nutrients, BOD_5, etc) are monitored on a weekly basis in all influent and effluent streams.

This paper presents data on the first full year's operation of the artificial marsh, including loadings, removal efficiencies and effluent qualities of the various systems.

Preliminary data suggest that artificial marshes have the capacity to improve the quality of partially treated wastewaters; the degree of improvement being dependent upon many factors including hydraulic loading, retention time, season and system configuration.

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1.0 INTRODUCTION

Effluent requirements within the Province of Ontario are determined under the provisions of a document "Water Management, Goals, Policies, Objectives and Implementation Procedure of the Ministry of the Environment"[1]. In accordance with the policies outlined in this publication, effluent requirements are established on a case-by-case basis considering the characteristics of the receiving water body, as well as Federal and Provincial effluent regulations and guidelines, if they apply.

For discharges from municipal and private sewage treatment works, Provincial jurisdiction applies, except for Federal facilities. Normally, however, the Federal government consults with the Province to ensure that the effluent from Federal plants will be consistent with Provincial policies. Secondary treatment is considered as the normal level of sewage treatment required in the absence of detailed receiving water assessments.

Sewage lagoons are a common means of secondary sewage treatment for the smaller communities of Ontario. Lagoons are popular in such situations because of their low capital and operating costs, simplicity of process and minimal maintenance requirements.

Frequently, however, such small communities are situated on small streams or rivers. The capacity of such receiving waters to accept sewage effluent is often limited by inadequate dilution during summer low flow periods. Such conditions can lead to excessive fertilization leading to nuisance proliferation of plants and algae, with attendant widely fluctuating oxygen levels. In addition, elevated ammonia and hydrogen sulphide concentrations in winter and early spring discharges from sewage lagoons frequently exceed levels toxic to fish.

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1. Ontario Ministry of the Environment Publication,,135 St. Clair Ave. W., Toronto, Ontario M4V 1P5

To overcome this problem, many sewage lagoon systems have been converted to, or were designed as, seasonal retention lagoons. These systems provide storage of lagoon contents during the low stream flow period of the summer to overcome inadequate dilution. In some instances, seasonal retention lagoons have been provided with low level, subsurface aeration for hydrogen sulphide control during the winter and early spring periods.

Sewage lagoons may also be replaced with mechanical, tertiary sewage treatment facilities to provide a high degree of treatment, thereby permitting year-round discharge.

Conversion of continuous discharge lagoons to seasonal retention lagoons, and expansion of the same, are very land consumptive and in many areas, compete for high value agricultural lands. Replacement of lagoons by mechanical plants is costly and frequently impractical for these small communities.

In recent years, the potential of aquaculture and land application approaches to wastewater treatment have received renewed and increasing attention in North America. It has been suggested that biological treatment systems, such as marshes and wetlands, are capable of removing organic and inorganic wastewater constituents, degrading toxic compounds such as phenols, and attenuating pathogenic organisms. To date, however, attention has largely focused on the use of natural wetlands for tertiary treatment purposes, while the development of artificial marshland treatment systems has received little attention to date. Artificial marshes, however, may be a viable solution for small communities where existing sewage lagoons could in part be converted to marsh treatment systems.

To assess the potential of artificial marshlands for upgrading sewage effluent to permit year-round discharge in Ontario, an experimental marshland facility was constructed in 1979 adjacent to the existing sewage works for the Town of Listowel. Detailed studies are being conducted to attempt to define both the effectiveness of, and optimum design and operational criteria for artificial marsh treatment systems.

This paper is not a literature review of works published to date, but is rather a description of the first full year's operation of the Listowel artificial marshland facility. The paper presents data, including loadings, effluent qualities and removal efficiencies of various parameters, and relates these to the various operational modes encountered. Preliminary conclusions relating to the potential of artificial marshlands for the further treatment of sewage effluents are made.

2.0 DESCRIPTION OF STUDY FACILITY

The sewage treatment works for the Town of Listowel is a sewage lagoon system consisting of an aeration cell of 3.5 days detention followed by two facultative lagoons, each with a detention time of 35 days at the present flow rate of some 5,448 m^3/day. The two lagoons can be operated either in series or in parallel and are currently operating in series. The influent wastewater consists of that from the light industrial Town of Listowel and that from a canning industry, with the canning industry producing about 58% of the flow and 78% of the BOD load.

Effluent discharge is continuous in the winter but because of restrictive receiving water conditions, no discharge is permitted during the period May through August. Consequently, the lagoons are drawn down in the early spring and once filled, the contents are spray irrigated on adjacent land. Aluminum sulphate is added at a concentration of about 60 mg/l to the raw sewage from September to May to provide phosphorus removal to an effluent value of <1 mg/l during the period of continuous discharge.

The existing facility is becoming hydraulically overloaded and projected population growth dictates facility expansion. Plans for expansion have attracted special attention since established methods of sewage treatment are unlikely to resolve all of the evident water quality problems in the receiving watercourse at a reasonable cost. This made Listowel a receptive candidate for the artificial marshland study.

Construction of the artificial marsh system commenced in the fall of 1979 and was completed in July of 1980. The facility, located adjacent to the existing lagoons, consists of five separate treatment systems and a small control marsh for monitoring rates of evapotranspiration (Figure 1). System I consists of a 2,120 m^2 open marsh, a 728 m^2 pond and a 1,000 m^2 channelled marsh totalling 334 m in length, all connected in series. The berms of the channelled marsh have been designed to accommodate a tractor with a cutting bar for purposes of harvesting the marsh vegetation, with the inside width of the channels being about 3 m. System II consists of a 1,000 m^2 open marsh and System III of 334 m of channels. Systems I, II and III receive wastewater from the east lagoon, the first of the two in series.

Systems IV and V are duplicates of Systems III and II but receive wastewater from the aeration cell outfall.

The 28 m^2 control marsh is lined with plastic to prevent exfiltration (or infiltration) and receives lagoon effluent. All the other cells, except the pond, were compacted, backfilled with a mixture of subsoil, topsoil and 10% peat by volume and planted with cattails, Typha spp. The pond was compacted and seeded with pondweeds, Potamogeton spp. and Elodea canadensis.

Wastewater from the east lagoon and aeration cell are pumped to separate flow-splitting chambers and fed by gravity to the various experimental cells. Flows are controlled by V-notch and rectangular weirs. All systems are extremely flexible being capable to operating at variable hydraulic loads, retention times and depths.

All marshes are capable of being operated at liquid depths varying from 5 to 30 cm. The pond is maintained at a liquid depth of 0.9 m.

Outflows from all experimental cells are monitored by V-notch weirs and water level recorders, whereas, the influent flows are set and maintained at constant rates. This is accomplished through the use of broad crested bypass weirs in the flow-splitting chambers. Effluents from all systems are collected in a wet well and can be discharged by gravity directly to the Chapman Drain which flows into the Middle Maitland River, however, if they are of unsuitable quality for direct discharge, they can be pumped back into the west lagoon. Combined flows from Systems I, II and III, and combined flows from Systems IV and V, can be handled separately in either of the above manners if desired.

A full instrumented weather station is equipped to monitor nutrient inputs from rain and snowfall.

To permit continuous winter operation of the systems, perforated pipes connected to an air blower were installed in the culverts connecting the channels of Systems I, III and IV. All effluent chambers were insulated and heated to prevent freezing and blockage of the outflow chambers and weirs.

3.0 SAMPLING PROCEDURES AND ANALYTICAL METHODS

Sampling stations were established at all outflow weirs and inside the flow-splitter chambers for the two influents. Routine parameters (i.e. BOD, SS, nutrients, temperature, pH, alkalinity, bacteria) are monitored weekly from April to November on grab samples and at 2 week intervals for the remainder of the year. Salmonella populations are assessed six times per year and *Clostridium perfringens* and *Yersinia enterocolitica* are monitored during the winter months. Heavy metals are monitored on monthly samples and PCB's and organochloride pesticides every six months. Analytical techniques used are as discussed elsewhere (Ontario Ministry of the Environment, 1981). Flow measuring and sampling locations are as identified on Figure 1.

4.0 OPERATION

Following completion of construction in July, 1980, the systems were fed their respective sewage effluents at a low rate and the marshes were planted with cattails, *Typha* spp. collected from local, natural marsh areas at approximately 1 m spacings. Within two months, the growth was dense and luxuriant, suggesting that cattails are ideally suited for this type of operation.

A liquid depth of 14 cm was selected for the initial phase of operation (August to December) in all units except the deep pond of System I. Hydraulic loadings during this period were monitored as close as possible to 90 m^3 day^{-1} for System I and 17 m^3 day^{-1} for the remaining systems. These loadings gave an 11 1/2 day retention period in System I, 7 3/4 days in Systems II and V and 8 3/4 days in Systems III and IV.

In early December, water depths in the marshes were increased to 28 cm with concurrent increases in hydraulic loadings in an attempt to prevent freezing during winter operation. These changes in operation reduced the retention time in System I to 7 1/2 days, in Systems II and V to 5 days and in Systems III and IV to 6 days.

During the latter part of December, 1980 aeration tubing was installed in the connecting culverts of the channeled marshes and heaters installed over the outflow chambers in anticipation of winter freezing problems. At this time, severe ice formation in the marshes had a drastic impact on their retention periods. By late January, 1981, retention times were reduced to less than 2-3 days in Systems II to V and to 3 1/2 days in System I.

In May of 1981, flows were readjusted to provide a nominal 7 day retention period and operating depth of 20 cm in all systems.

On July 24, 1981, the flows were once again adjusted, this time to provide the same retention times used in the fall period of 1980. Liquid depth was maintained at 20 cm. Dye tests carried out on the marsh systems in early July had determined the retention times to be considerably less than those calculated from volumes. It was then realized that the stalks of the dense cattails reduced the marsh volumes by between 1/3 and 1/2 the calculated values. Actual flow rates and calculated retention times are presented later in Section 5.0, Table 1.

As mentioned previously, the channelled marshes were designed to permit harvesting. A specially designed tractor mounted harvester, consisting of a cutting bar and conveyor, was constructed for harvesting the channelled systems. The conveyor transports the cut stalks to the berm behind the harvester.

The fourth and fifth channels of Systems III and IV were harvested on July 16, 1981. The first three channels of these same systems were later harvested on August 26, 1981. Harvesting was carried out on these dates to compare the amounts of nutrients removed and the extent and quality of regrowth occurring. Special sampling was also conducted in an attempt to assess the effect of harvesting on effluent quality. The harvested cattails were weighed and sampled for nutrient and heavy metal analyses.

5.0 RESULTS AND DISCUSSION

Although general comments will be made in this and the following sections, which may address anyone, or all of the marsh systems, detailed assessments will only be made of Systems II, III, IV and V. The complexity of System I makes any interim assessment of its operation very difficult in this, its first year of operation.

It should be noted that for purposes of this paper, gross assessments of only the more conventional parameters have been made. The complexity of operating variables during this initial phase of operation of the marsh, make the results to date quite preliminary in nature. Further long term studies are required to confirm the conclusions drawn.

Flows for this paper have been estimated from bucket discharge readings rather than digitized flow records. However, since these readings were normally taken in the first half of the day, outflow volumes will be overestimated since the readings will not have been influenced by afternoon evapotranspiration. Consequently, any calculated removal efficiencies are on the conservative side.

Data are presented both in concentrations and mass loadings, however, in determining removal efficiencies, mass values rather than concentrations have been used. Rainfall and evapotranspiration within the relatively large surface areas of the marshes significantly affected outflow volumes, which ranged from as high as 160% to as low as 30% of the influent volumes on any particular day.

Although influent and effluent concentrations have been presented in tables on the basis of monthly averages of weekly values, mass loadings and removal efficiencies were calculated on a period basis. As mentioned in Section 4.0, the operation program to date has involved four distinct flow regimes. These flow regimes were used as the basis for selection of the four study periods and Table 1 provides pertinent identification of each. Period 2 has been divided into Period 2A and Period 2B on the basis of temperature, with 2A occurring at the severest time of the year.

As previously mentioned, Systems I, II and III are fed from the east lagoon, while Systems IV and V receive aeration cell effluent[1]. The quality of the feed to Systems I, II and III is presented in Table 2, while that to Systems IV and V is given in Table 3. Effluent concentrations of the same parameters from Systems II to V are presented in Tables 4 to 7, respectively.

Tables 8 to 11 present influent and effluent mass loadings as well as percent removals for selected parameters for the four flow periods for System II to V.

These tables are discussed in the following sections.

5.1 <u>Temperature</u>

Average influent temperatures for each period are presented in Table 1. Summer temperatures were quite similar in both feed streams with a single day high in August of 26°C. Winter temperatures

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[1] note: From this point on, the feed stream from the aeration cell will be termed aeration cell influent while that from the lagoon will be termed lagoon influent.

in the aeration cell influent were, however, consistently several degrees higher than were those of the lagoon influent as would be expected. January temperatures of the lagoon influent hovered just above $0^{\circ}C$ while the minimum recorded temperature of the aeration cell influent was $3.5^{\circ}C$.

Temperatures of all marsh effluents were very similar and closely followed those of the lagoon influent and measured as $0^{\circ}C$ for most of January.

5.2 Dissolved Oxygen

Dissolved oxygen concentrations in the lagoon influent have not followed the classical seasonal trends of summer high and winter low values. This is likely because of the location of the pump inlet which is at the bottom of the lagoon where, except for periods of extensive algae blooms, or at times of wind-caused turnover, DO values would be expected to be, and indeed were, very low. Throughout June and July, 1981 (data not presented), the lagoon influent rarely contained any measurable DO, while during October and November, 1980 it frequently exceeded 10 mg/l. Dissolved oxygen values fluctuated between 0 and 3 mg/l throughout the winter. The pump inlet was situated at the bottom of the lagoon to eliminate any winter freezing problems and because the lagoon contents are drawn down in the spring. It is intended that a floating inlet structure be constructed for use in subsequent summers.

Low summertime DO levels close to 0 mg/L in the aeration cell influent reflect the insufficient capacity of the existing aeration equipment during peak summer loading periods. Even during the winter period, DO levels in this feed stream seldom exceeded 3 mg/l.

All experimental marsh systems initially followed classical seasonal DO trends with high values in the fall and winter values ranging between 0 and 7 mg/l. The winter values of the channelled Systems III and IV were slightly higher than the open marsh Systems II and V, no doubt reflecting the oxygen contribution from the air blower which was used to prevent freezing in the channelled marsh connecting culverts. Total anoxia occurred in Systems II and V for a short period in late January. Anoxic conditions occurred again during the latter part of June, all of July and most of August in Systems II and V and from mid-July into early August in Systems III and IV. The latter conditions can be attributed in part to the extremely dense layer of duckweed which developed on the surfaces of all marsh systems during the summer of 1981 and the sludge mats which formed on the inlet ends of Systems IV and V (see Section 5.4). Also, the high evapotranspiration rates during July and August and short-circuiting, especially in the open marshes, caused by the dense cattail growth, probably led to stagnant areas and severe anaerobic conditions. This condition is very significant when assessing treatment efficiencies later in this paper.

5.3 Five-Day Biochemical Oxygen Demand (BOD)

The aeration cell influent feed was characterized by highly variable BOD concentrations which frequently exceeded 100 mg/l as shown in Figure 2. This variability was significantly attenuated during passage of the wastewater through Systems IV and V. Effluent values were consistently below 5 mg/l during the fall of 1980 but increased to as high as 30 in January/February. Except for one odd value on June 2, 1981, System IV consistently outperformed that of open System V.

Figure 4 presents a graph of percent BOD removal in each of the systems for the four study periods. This figure also reflects the improved performance of the channeled systems. Other than the low value of System II during the winter, significant BOD reductions were realized in all systems; the higher reductions of Systems IV and V being no doubt due to the higher influent concentrations of their feed stream.

5.4 Suspended Solids (SS)

Graphs of weekly SS data for the influent and effluents of Systems IV and V are presented in Figure 5 and those for Systems II and III in Figure 6. As with BOD, SS concentrations in the aeration cell influent were quite high and variable but followed a seasonal trend with low values during the winter/spring period. This was also the period of alum addition to the raw sewage for phosphorus removal purposes, but this should not have reduced aeration cell solids levels. Reduced biological activity under cold conditions and weaker strength sewage, may have been the causes.

The high solids loadings to Systems IV and V resulted in the development of dense sludge mats at the influent ends of these marshes. By springtime, considerable dieback of Typha spp. had occurred in the sludge mat areas and some hydrogen sulphide production was noticed. Recovery of the cattails continued throughout the summer period.

Effluent SS concentrations in Systems IV and V were generally less than 15 mg/l although some higher values occurred in June/July, especially in System V.

Concentrations of SS in the influents to Systems II and III were generally less than 25 mg/l except for peaks in the late spring/ summer period. These peaks coincided with phytoplankton blooms in the facultative lagoon when chlorophyll concentrations approached 200 µg/L.

Effluent SS concentrations in the two systems were similar with some deterioration in quality, again particularly in the open marsh (System II), occurring in the summer period.

Trends in SS percent removals for the four study periods are presented in Figure 7. Again, the channelled marshes outperformed the open marshes although both Systems II and III experienced low percent removal values during Periods 2 and 3.

5.5 Phosphorus (P)

Weekly values of Total Phosphorus (TP) concentrations in the influents and effluents of the marshes are shown in Figures 8 and 9. Concentrations generally ranged between 2 and 6 mg/l in the aeration cell influent and 1 and 2 mg/l in the lagoon influent. As mentioned, chemical addition for phosphorus removal is practiced from September to May and consequently, the phosphorus level within the lagoon was lower during this period (except again for one odd value on April 14). The similarly lower values in the aeration cell influent during this period probably reflect weaker sewage strengths during the winter period.

Effluent TP concentrations of all systems tended to follow expected seasonal trends with peak values occurring in the colder winter months, however, all values begain increasing again in June. In fact, for a short period in August, 1981 there was a net loss in TP from System II. System IV was the only system which provided a relatively consistent effluent with respect to TP concentration.

The poor performance of Systems II, III and V in the summer/fall of 1981 may be explained by the discussions regarding DO in Section 4.2. Anoxic conditions undoubtedly led to the release of phosphorus which had been bound in the marshes. Aeration tubing was installed along the length of the final channel of System IV during July and August, 1981 on an experimental basis and although no measurable DO level was achieved, perhaps adequate conditions were provided to prevent the release of phosphorus evident in the other systems.

Soluble Reactive Phosphorus (SRP) concentrations in all system influents and effluents are presented in Figures 10 and 11. Of note in both influents, is the decrease in SRP concentration during the chemical addition period, indicating the effective precipitation of soluble phosphorus.

Percent removals of TP and SRP are presented in Figures 12 and 13, respectively. Again, the high removals of both TP and SRP in Period 1 dropped off considerably during the winter period for all systems, although the higher removals of TP in Systems IV and V are undoubtedly due to the precipitation in the marshes of chemically bound phosphorus. System V showed negative reductions of SRP in both the winter and spring periods of Period 2, while removals of both TP and SRP dropped off again in System II and to a lesser extent in System V during Period 4.

Once again, the channelled marshes outperformed the open marshes with respect to both Total and Soluble Reactive Phosphorus.

5.6 Nitrogen (N)

Total Nitrogen (TN) concentrations in the aeration cell influent fluctuated between 10 and 37 mg/l and showed little seasonal trend (Figure 14). Although less variation occurred in the lagoon influent (Figure 15), peaks occurred in January, April and July.

Total Nitrogen concentrations in the effluents of all four experimental marshes were remarkably similar and generally followed influent concentration trends until the late summer, 1981 period. At this time, TN concentrations in the effluents of the two open marshes (Systems II and V) increased significantly.

Nitrites and Nitrates comprised an insignificant portion of the Total Nitrogen of both influents and effluents of all systems (Tables 2 to 7).

Ammonia concentrations, on the other hand, comprised a significant percentage of the Total Nitrogen in the two influent streams (Tables 2 to 7) and were similar in both although slightly lower in the lagoon influent, reaching a minimum average value of 1.4 mg/l for May. As with TN, Ammonia concentrations in all marsh effluents were very low (<1 mg/l) during the fall/early winter of 1980, increased considerably during the winter period, decreased again in early summer and once more increased in late summer, 1981.

Again, the effluent Ammonia concentrations were consistently lower in the effluents from the channelled marshes than the open marshes.

As can be seen from Figures 16 and 17, both Total and Ammonia Nitrogen removals followed similar patterns to the other parameters.

6.0 GENERAL OBSERVATIONS

The following observations of specific and general aspects of the operation of the study facility provide an insight into the treatment which may be expected from an artificial marsh of this nature, and may be used to help clarify some of the tentative conclusions which have been drawn from the preliminary phase of this study.

6.1 System Configuration

The data collected to date on the artificial marsh systems demonstrate the superior performance of the channelled marsh over the open marsh of equal surface area. It would appear that this superior performance is due to the greater use of the total marsh volume, the channels reducing the degree of short-circuiting and resulting in reduced loadings on subsequent channels, leading to higher effluent quality.

The ideal marsh system would ensure uniform flow across the full surface area of the marsh as well as providing for continuous movement of the liquid in the marsh. Even distribution of the influent feed across the marsh is essential and may best be accomplished by the use of perforated irrigation pipe across the influent end of the marsh. Perhaps intermittent baffles along the length of the marsh could be used to improve circulation within the marsh and reduce short-circuiting.

6.2 Retention Time

Although not readily visible because of the manner in which the data have been presented, retention time seems to have a strong influence on effluent quality; with effluent quality deteriorating

at both too short and too lengthy a retention period. Best treatment results coincide with retention times of between 7 and 10 days, achieved in the fall of 1980 and early summer of 1981.

The shortest retention time occurred in the coldest period of the year (Table 1) when the entire facility was ice and snow covered and treatment efficiency would have been expected to be low. The retention time during mid-summer was also low because of the profuse cattail growth and the higher efficiencies of the early summer period quickly deteriorated. Treatment picked up again in the early fall as flows were reduced but dropped off again as retention periods became too long (≈18 days) due to high rates of evapotranspiration. The long retention period leads to stagnation and subsequent anoxia with the potential release of bound Nitrogen and Phosphorus.

When establishing flow rates and retention times, one must consider many factors other than marsh area and depth. Other factors include cattail growth, ice layer in winter, rainfall and evapotranspiration.

6.3 Pretreatment

Problems experienced with the operation of the artificial marsh systems fed with aeration cell influent appear to have been caused by its high suspended solids content. These formed sludge mats at the influent ends of the marshes killing back the vegetation and leading to hydrogen sulphide formation. The higher loadings of BOD, Phosphorus and Nitrogen appeared to have little adverse effect on effluent quality.

For artificial marshes it is therefore suggested that the minimum form of pretreatment include solids removal by clarification to the equivalent of primary effluent quality.

6.4 Harvesting

Harvesting of different channels of Systems III and IV was carried out on July 16 and on August 26, at which times the cattails averaged approximately 3 and 3.2 meters in height, respectively. The mass of cattails and associated Nitrogen and Phosphorus removed are given below:

Harvest Date	Dry Weight (kg/channel)	Mass Removed (kg/ha) N	P
July 16, 1981	86	150	17
August 26, 1981	209	366	42

As can be seen, the August harvest removed over twice the amount of material than did the July harvest although each removed a significant amount of nutrients. Using the August harvesting data and comparing the mass of Nitrogen and Phosphorus removed to the mass fed to System III in the lagoon influent, it can be calculated that the August harvest removed the equivalent of 70 days loading of Nitrogen and 84 days loading of Phosphorus.

The common cattail, Typha spp. has been found to be an ideal vegetation for use in artificial marshlands for sewage effluent treatment. The Listowel marshes were planted with cattail shoots collected from local ditch areas, which adapted well to the sewage environment reaching heights considerably in excess to native growths. When harvested, the cattails removed a significant amount of nutrients and regrowth was exceptional, with the cattails regrowing at the rate of about 12 cm per week.

No estimation can be made at this time, of the effect of harvesting on marsh effluent quality. However, in view of the rapid rate of regrowth and substantial quantities of nutrients removed, it is anticipated that harvesting would have an immediate and overall positive impact on the marsh performance.

Marsh performance may be further improved by the harvesting of cattails twice per year. An early summer cut would remove lesser amounts of biomass but would stimulate rapid growth. A second cut in late summer or early fall would remove the summer's biomass and contained nutrients prior to plant senescence in late fall.

6.5 Bacterial Reduction

As mentioned, the raw sewage entering the Town of Listowel's wastewater treatment facility contains a significant contribution of flow from a local food (primarily poultry) processing industry. Consequently, the sewage contains exceptionally high levels of fecal coliforms, fecal streptococci and salmonella bacteria, particularly during the winter months.

Figures 18 and 19 present graphs of influent and effluent fecal coliforms and fecal streptococci for each of the five systems. As illustrated, considerable reductions in both forms of bacteria were evident in all marsh systems in the fall and spring periods. Treatment efficiency, however, decreased significantly during the winter, especially in the open marsh systems.

In general, the bacterial quality of the marsh outflows was comparable to the quality of disinfected secondary effluent except during the winter months. Again, the channelled marshes (Systems II and IV) exhibited superior treatment to the open marshes, especially throughout the winter months.

Although salmonella were characteristically recovered from the aeration cell and lagoon influents, the organism was only very infrequently found in the effluents of Systems II, III and IV.

6.6 Cost of the Artificial Marsh System

The total engineering and construction cost of the Listowel Artificial Marsh System was approximately $284,000. This cost, however, included many items and specifications specifically for research purposes. For example, the bottoms of the marsh systems were levelled by a laser to within $\pm$ 2.5 cm; influent and effluent flow control and measuring stations were established for all marshes; a lined control marsh was provided; and observation wells for ground-water monitoring were provided.

Subtracting out those costs incurred solely for research and specific monitoring purposes, it is estimated that the capital costs of a channelled marsh system to treat a flow of 4545 m^3/day would cost approximately $400,000 exclusive of land costs. Operational costs would be minimal requiring little more than pump maintenance and once per year harvesting.

7.0 CONCLUSIONS

Preliminary water quality data from the Listowel Artificial Marsh suggest that artificial marshes have the capacity to significantly improve the quality of partially treated wastewaters. Although a much longer study period is required to assess long-term performance, and to establish optimal design and operational criteria, the following conclusions can be drawn from the study to date:

a) As evidenced by the rapid growth of the cattail *Typha* spp. following initial planting, the common cattail is well adapted to the sewage environment. Regrowth rates and the density and height of growth attained confirm this.

b) System configuration is very important with channelled marshes providing superior treatment to open marshes. Even distribution of the influent sewage flow is essential, along with continuous flow across the entire surface area of the marsh to eliminate short-circuiting and formation of stagnant areas.

c) Retention time of the sewage within the marsh is also critical, with too low a retention time decreasing treatment efficiency due to insufficient contact, and too lengthy a retention time leading to stagnation and anoxic conditions. This study to date would suggest an optimum retention period of from 7 to 10 days at an operating depth of about 20 cm.

d) The artificial marsh is capable of accepting, and improving the quality of both partially treated sewage and sewage of secondary quality. While effluent quality of the marsh is partially dependent upon influent quality, treatment efficiency appears to be more dependent upon such factors as retention time, degree of short-circuiting and stagnation, temperature and flow rate than actual mass loading. High levels of suspended solids can lead to sludge accumulation with resultant reduced treatment and should be removed prior to the marsh.

e) The artificial marsh appears capable of reducing bacterial levels in sewage effluent to the equivalent of disinfected secondary effluent except perhaps during the coldest winter months.

f) Reduced winter performance was no doubt partly influenced by the high hydraulic loadings and short retention times. Additional information, at reduced flows with concomitant longer retention times, is required to properly assess the winter capabilities of the artificial marsh process. Even so, System III, the channelled marsh treating lagoon influent, achieved BOD, TP and TN reductions of 56, 35 and 25%, respectively, during the 1980/1981 winter period. Similarly, System IV treating aeration cell influent achieved BOD, TP and TN reductions of 79, 71 and 30%, respectively, for the same period.

g) Harvesting of cattails is a potential marsh management option and it is suggested that two harvestings be carried out per year. An early summer harvest will stimulate rapid cattail growth, and one in early fall will remove the summer's biomass and significant amounts of nitrogen and phosphorus from the system.

TABLE 1

Characteristics Of Study Period

Period	Dates	Influent Temp. (°C)	Depth (cm)	Average Flow (m^3/day)	Nominal Retention (days)	Calculated* Retention (days)
1	July 14-Dec. 6					
	System II	12.9	14	18.2	7.07	6.4
	III	12.9	14	17.7	7.95	7.2
	IV	17.5	14	16.5	8.54	7.5
	V	17.5	14	18.0	7.16	6.5
2A	Dec. 7-Feb. 28					
	System II	1.6	28	65.9	4.0	2.0
	III	1.6	28	67.4	4.6	2.3
	IV	6.4	28	51.6	6.0	3.0
	V	6.4	28	54.5	4.8	2.4
2B	March 1-April 30					
	System II	7.7	28	77.3	3.4	2.8
	III	7.7	28	79.7	3.9	3.4
	IV	10.2	28	49.9	6.2	5.2
	V	10.2	28	52.6	5.0	4.3
3	May 1-July 24					
	System II	19.7	20	33.3	5.6	4.0
	III	19.7	20	38.2	5.5	3.8
	IV	19.4	20	32.3	6.5	4.4
	V	19.4	20	28.1	6.6	4.6
4	July 25-Sept. 1					
	System II	23.0	20	17.5	10.6	13.3
	III	23.0	20	16.6	12.6	18.9
	IV	21.5	20	18.2	11.5	18.9
	V	21.5	20	17.6	10.6	16.3

* Calculated value considers volume reduction due to cattail growth and ice layer during winter, rainfall, evapo-transpiration and limited dye tracer data.

TABLE 2

Lagoon Influent Quality - Feed to Systems I, II and III

(Monthly Averages Based Upon Weekly Grab Samples)

Date	BOD_5	SS	TP	SRP	TKN	NO_2+NO_3	NH_3
				mg/l			
Aug., 1980	11	22	1.9	1.6	12	0.4	6.7
Sept.	18	23	1.8	1.3	8	1.0	3.4
Oct.	11	8.4	1.1	0.7	8	0.4	3.9
Nov.	12	9.7	0.9	0.4	9	0.3	4.7
Dec.	14	23	0.8	0.3	10	0.3	5.2
Jan., 1981	25	15	1.0	0.5	14	<0.01	9.4
Feb.	33	18	1.1	0.7	15	<0.01	10.1
Mar.	27	14	1.0	0.24	12	<0.01	7.3
April	29	63	0.9	0.16	14	0.12	5.6
May	42	36	1.1	0.15	10	0.06	1.4
June	26	29	1.6	0.85	16	0.03	8.8
July	13	18	1.9	1.26	16	0.03	11.3
Aug.	12	18	2.2	1.52	14	0.15	9.7

TABLE 3

Aeration Cell Influent Quality - Feed to Systems IV and V

(Monthly Averages Based Upon Weekly Grab Samples)

Date	BOD_5	SS	TP	SRP	TKN	NO_2+NO_3	NH_3
				mg/l			
Aug., 1980	39	80	2.3	2.55	19	1.35	10.4
Sept.	64	182	3.7	0.35	21	0.68	7.3
Oct.	52	190	4.9	0.09	24	0.32	7.9
Nov.	97	189	4.7	0.07	23	0.02	4.9
Dec.	68	59	2.4	0.16	15	0.01	5.2
Jan., 1981	72	88	3.2	0.16	24	<0.01	11.0
Feb.	91	46	1.9	0.13	13	<0.01	7.5
Mar.	53	56	2.8	0.31	15	<0.01	6.0
April	38	54	1.9	0.16	16	0.01	7.1
May	90	160	5.0	0.90	28	0.01	8.2
June	105	221	6.8	1.20	29	<0.01	9.3
July	56	162	5.1	1.47	25	<0.01	12.2
Aug.	26	66	3.7	2.25	20	0.45	14.3

TABLE 4

Marsh System II Effluent Characteristics
(Monthly Averages Based Upon Weekly Grab Samples)

Date	BOD	SS	TP	SRP	TKN	NO_2+NO_3	NH_3
				mg/l			
Aug., 1980	17	90	0.58	0.47	3.1	0.26	0.83
Sept.	5	10	0.29	0.19	2.9	0.01	0.3
Oct.	2	1	0.10	0.07	1.47	0.18	0.006
Nov.	5	5	0.16	0.07	1.89	1.16	0.013
Dec.	11	24	0.46	0.18	6.65	0.53	3.16
Jan., 1981	20	14	0.93	0.50	13.3	0.01	9.0
Feb.	32	14	0.96	0.38	13.0	0.06	7.4
Mar.	23	10	0.69	0.33	9.1	0.02	6.2
April	17	19	0.52	0.08	7.4	0.21	4.0
May	5	10	0.49	0.18	5.3	0.04	0.56
June	13	18	0.75	0.36	9.4	0	4.82
July	24	43	1.14	0.33	14.2	0	8.4
Aug.	9	7	2.42	2.58	13.0	0.01	11.1

TABLE 5

Marsh System III Effluent Characteristics
(Monthly Averages Based Upon Weekly Grab Samples)

Date	BOD	SS	TP	SRP	ZKN	NO_2+NO_3	NH_3
				mg/L			
August 1980	8	13	0.55	0.31	5.3	0.29	0.33
Sept.	5	11	0.18	0.09	2.7	0.02	0.20
Oct.	1.4	2	0.10	0.09	1.4	0.01	0.01
Nov.	2.4	3	0.12	0.07	1.6	0.98	0.02
Dec.	8	11	0.43	0.16	5.9	0.63	2.60
Jan. 1981	9.2	10	0.70	0.41	12.6	0.06	6.68
Feb.	15	19	0.84	0.42	12.1	0.02	7.47
March	12	9	0.52	0.39	8.9	0.01	6.62
April	18	24	0.60	0.10	7.3	0.30	2.9
May	6	8	0.27	0.14	4.7	0.02	0.28
June	10	14	0.41	0.19	7.1	0	4.27
July	16	31	0.79	0.18	12.1	0	6.72
August	10	10	1.02	0.68	7.8	0.01	4.12

TABLE 6

Marsh System IV Effluent Characteristics
(Monthly Averages Based Upon Weekly Grab Samples)

Date	BOD	SS	TP	SRP mg/L	TKN	NO_2+NO_3	NH_3
August 1980	-	-	-	-	-	-	-
Sept.	2.8	5.2	0.06	0.04	1.4	0.16	0.10
Oct.	1.8	1.1	0.05	0.02	1.3	1.02	0.19
Nov.	3.2	4.4	0.11	0.03	1.5	1.46	0.07
Dec.	15	3.6	0.51	0.08	8.0	0.24	4.4
Jan. 1981	22	9	0.92	0.31	16.7	0.02	11.7
Feb.	10	7	0.67	0.34	10.4	0.01	6.2
March	18	12	0.80	0.30	9.5	0.01	5.4
April	9	8	0.45	0.13	7.3	0.10	2.3
May	14	14	0.67	0.30	7.8	0.07	1.9
June	34	34	1.81	0.65	15.0	0	7.9
July	9	9.1	0.97	0.53	11.9	0	8.8
August	9	7	0.52	0.33	7.5	0.01	5.5

TABLE 7

Marsh System V Effluent Characteristics
(Monthly Averages Based Upon Weekly Grab Samples)

Date	BOD	SS	TP	SRP mg/L	TKN	NO_2+NO_3	NH_3
August 1980	2.4	9	0.22	0.16	2.8	0.29	0.24
Sept.	2.6	5	0.12	0.09	1.7	0.03	0.27
Oct.	2.2	1	0.08	0.02	1.5	0.74	0.22
Nov.	4.8	6	0.21	0.03	2.9	0.33	0.67
Dec.	15	5	0.61	0.12	9.0	0.44	5.1
Jan. 1981	25	13	1.19	0.17	17.9	0.03	6.4
Feb.	18	12	0.87	0.30	11.2	0.42	5.9
March	26	13	1.02	0.43	10.0	0.01	4.4
April	12	9	0.65	0.11	10.2	0.04	4.2
May	36	20	0.94	0.31	13.3	0.01	1.6
June	35	31	1.61	0.82	16.2	0	8.3
July	29	7	2.03	0.84	23.3	0	13.1
August	8	8	2.50	2.22	15.5	0.01	15.5

TABLE 8

Mass Loadings* And Percent Reductions - System II

	BOD	SS	TP	SRP	TN	NH_3
Period 1						
Influent	237	292	25.5	18	179	86
Effluent	41	84	2.7	2	40	0.7
% Reduction	83	71	89	89	78	99
Period 2A						
Influent	1581	1252	63	34	857	540
Effluent	1477	1125	55	25	780	457
% Reduction	7	10	13	26	9	15
Period 2B						
Influent	2319	1237	85	38	1082	672
Effluent	1516	1137	45	15	621	386
% Reduction	35	8	47	60	43	42
Period 3						
Influent	899	932	50	17	466	240
Effluent	576	875	29	10	359	179
% Reduction	36	6	42	41	23	25
Period 4						
Influent	210	316	39	27	245	170
Effluent	120	93	32.2	28	173	148
% Reduction	43	70	17	neg.	29	13

* Mass Loadings are in grams/day.
To convert to kg/ha/day multiply by 10^{-2}.

TABLE 9

Mass Loadings* And Percent Reductions - System III

	BOD	SS	TP	SRP	TN	NH_3
Period 1						
Influent	230	292	25.5	18.2	179	86
Effluent	35	52	1.7	1.2	25	0.7
% Reduction	85	82	93	94	86	99
Period 2A						
Influent	1618	1281	65	34	876	552
Effluent	705	833	42	21	654	359
% Reduction	56	35	35	38	25	35
Period 2B						
Influent	2391	1275	88	39	1116	693
Effluent	1024	1093	38	17	553	328
% Reduction	57	14	57	56	50	53
Period 3						
Influent	1031	1070	57	19	535	275
Effluent	397	639	18	6	288	143
% Reduction	61	40	68	68	46	48
Period 4						
Influent	199	299	37	25	232	161
Effluent	111	111	11	6	86	46
% Reduction	44	63	70	76	63	71

* Mass Loadings are in grams/day.
To convert to kg/ha/day multiply by 10^{-2}.

TABLE 10

Mass Loadings* And Percent Reductions - System IV

	BOD	SS	TP	SRP	TN	NH_3
Period 1						
Influent	1040	2640	64	12.5	363	125
Effluent	31	41	0.8	0.4	25	1.5
% Reduction	97	98	99	97	93	99
Period 2A						
Influent	3973	3302	129	8	877	408
Effluent	844	317	37	13	617	390
% Reduction	79	90	71	neg.	30	4
Period 2B						
Influent	2246	2745	140	12	798	324
Effluent	577	412	26	9	346	160
% Reduction	74	85	81	25	57	51
Period 3						
Influent	2713	5846	181	38.4	872	320
Effluent	599	602	37	15.1	346	201
% Reduction	78	90	80	62	60	39
Period 4						
Influent	474	1204	68	41	364	260
Effluent	99	77	6	3	83	61
% Reduction	79	94	91	92	77	76

* Mass Loading are in grams/day.
To convert to kg/ha/day multiply by 10^{-2}.

TABLE 11

Mass Loading* And Percent Reductions - System V

	BOD	SS	TP	SRP	TN	NH_3
Period 1						
Influent	1134	2880	70	13.6	396	137
Effluent	48	63	2	0.6	38.5	5
% Reduction	96	8	98	95	90	96
Period 2A						
Influent	4197	3488	136	8.2	926	430
Effluent	1010	532	47	10	676	308
% Reduction	76	85	65	neg.	27	28
Period 2B						
Influent	2452	2998	153	13	872	354
Effluent	940	544	41	13	500	213
% Reduction	62	82	73	0	43	40
Period 3						
Influent	2360	5086	157	33.4	759	278
Effluent	975	1287	46	17.4	521	240
% Reduction	59	75	71	48	31	14
Period 4						
Influent	458	1162	65	40	352	252
Effluent	91	91	28	23	177	177
% Reduction	80	92	56	42	50	30

* Mass Loading are in grams/day.
To convert to kg/ha/day multiply by 10^{-2}.

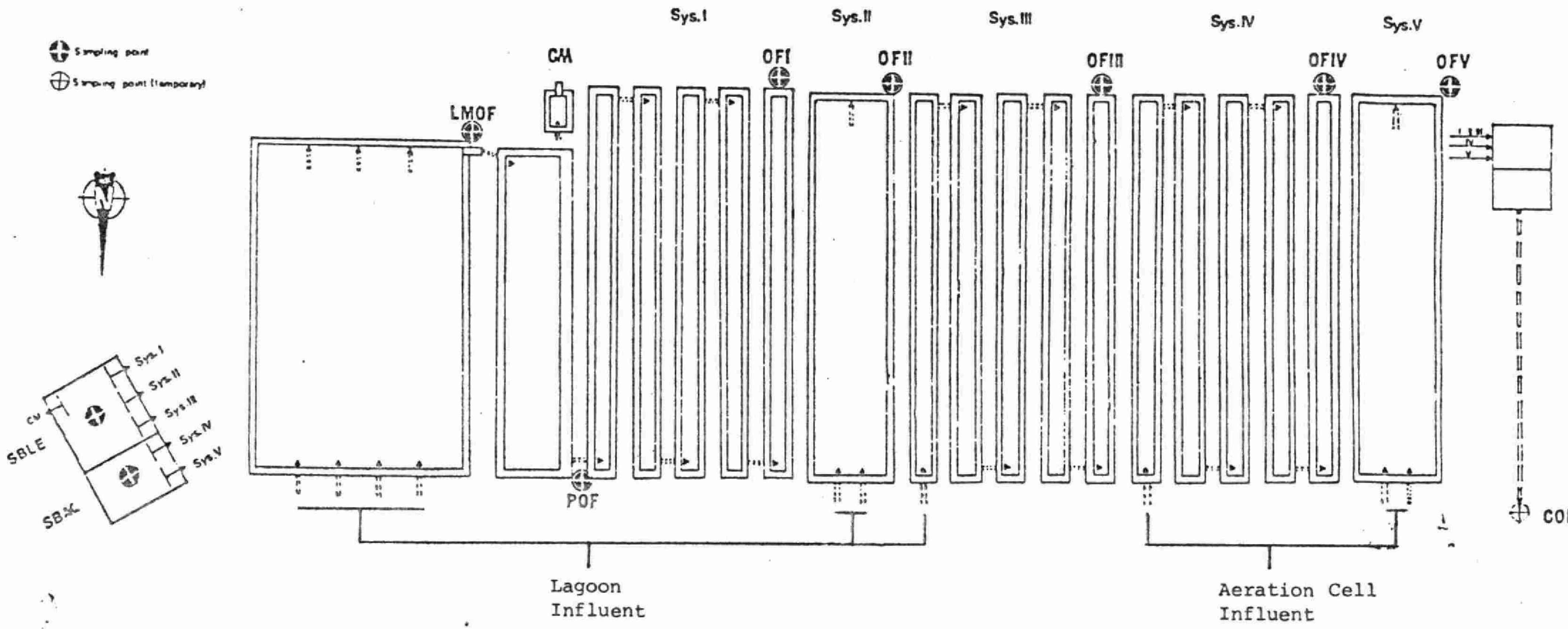


FIGURE 1 - LISTOWEL ARTIFICIAL MARSH FACILITY

FIGURE 2 - SYSTEMS IV AND V INFLUENT AND EFFLUENT BOD CONCENTRATIONS

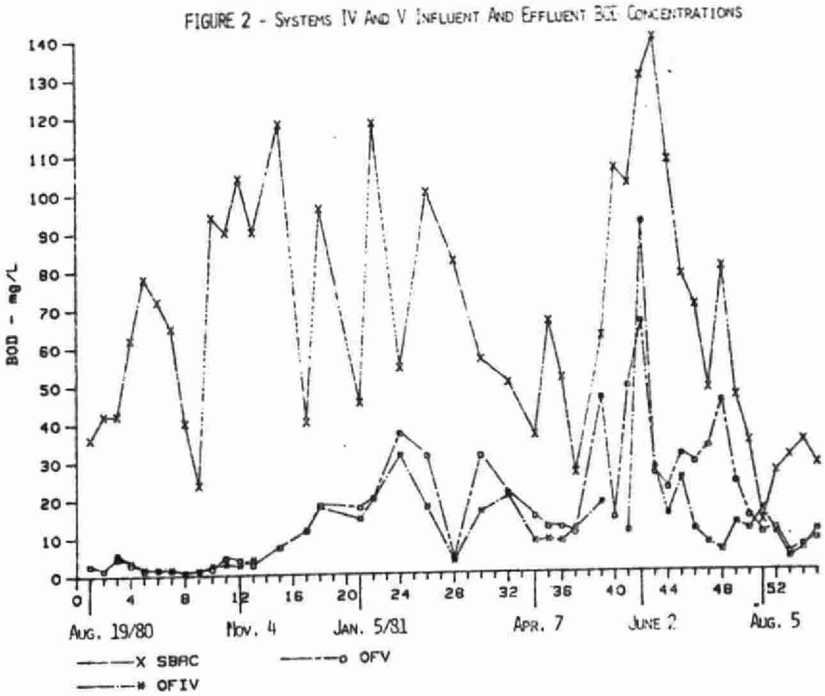


FIGURE 3 - SYSTEMS II AND III INFLUENT AND EFFLUENT BOD CONCENTRATIONS

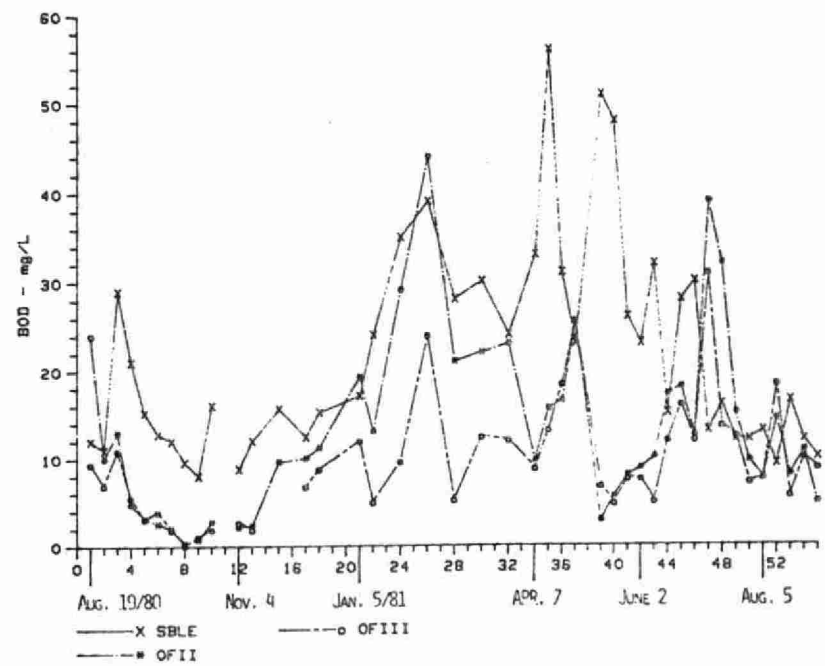


FIGURE 4 - PERCENT BOD REMOVALS FOR SYSTEMS II TO V

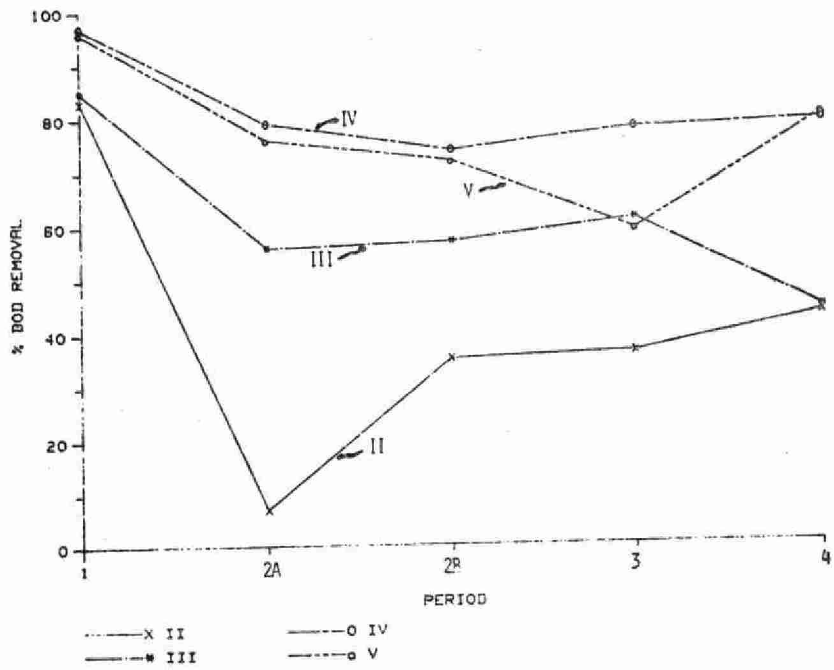


FIGURE 5 - SYSTEMS IV AND V INFLUENT AND EFFLUENT SS CONCENTRATIONS

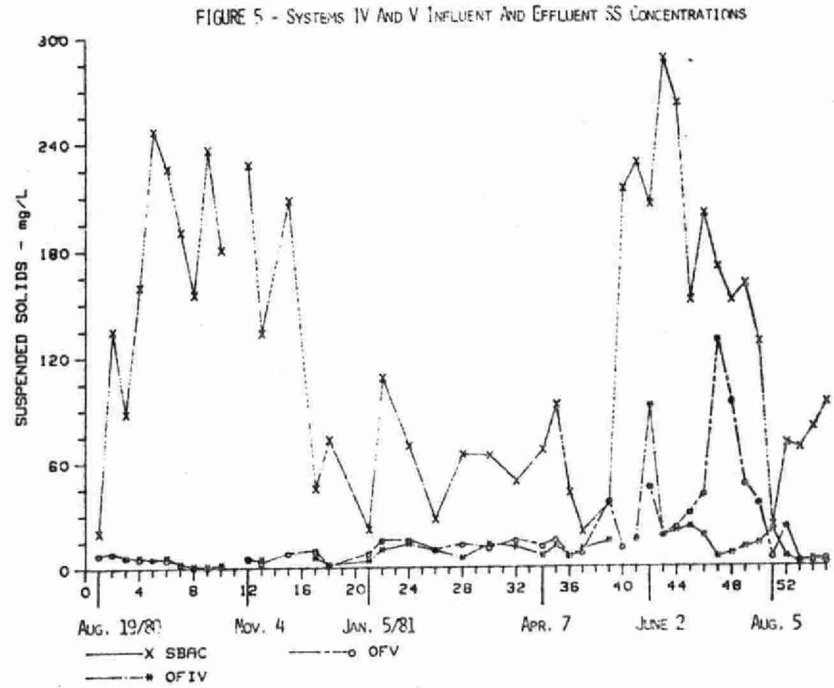


FIGURE 6 - SYSTEMS II AND III INFLUENT AND EFFLUENT SS CONCENTRATIONS

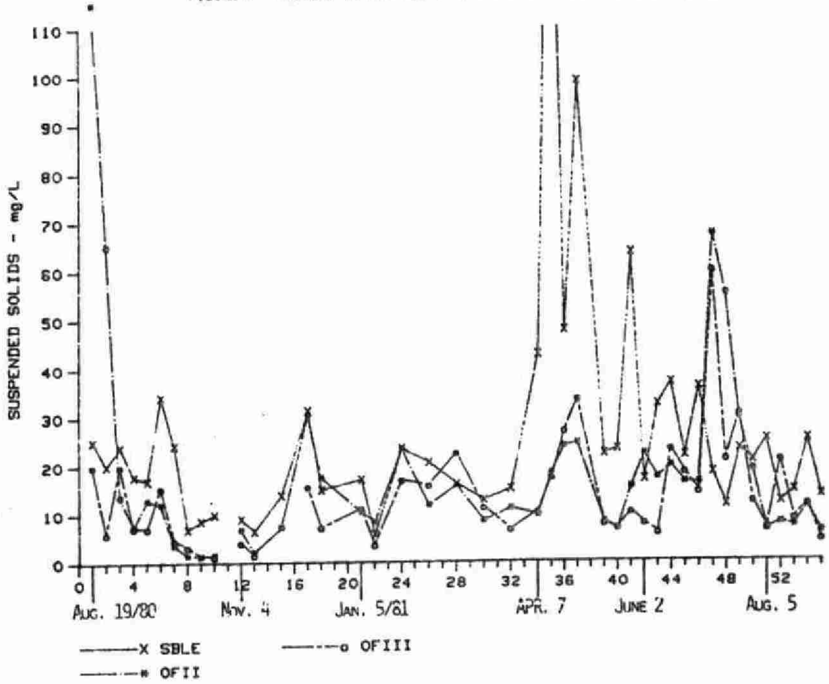


FIGURE 7 - PERCENT SS REMOVALS FOR SYSTEMS II TO V

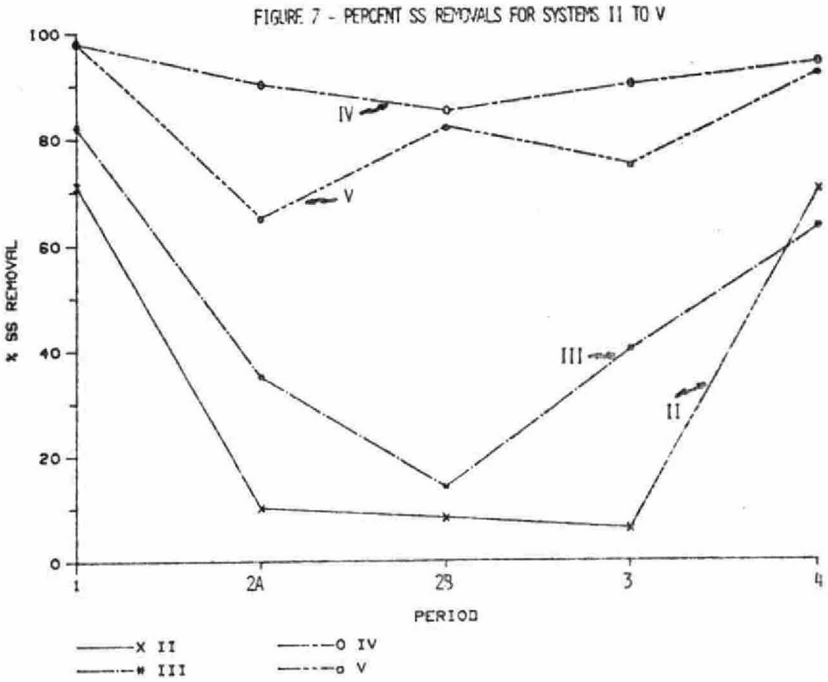


FIGURE 8 - SYSTEMS IV AND V INFLUENT AND EFFLUENT TP CONCENTRATIONS

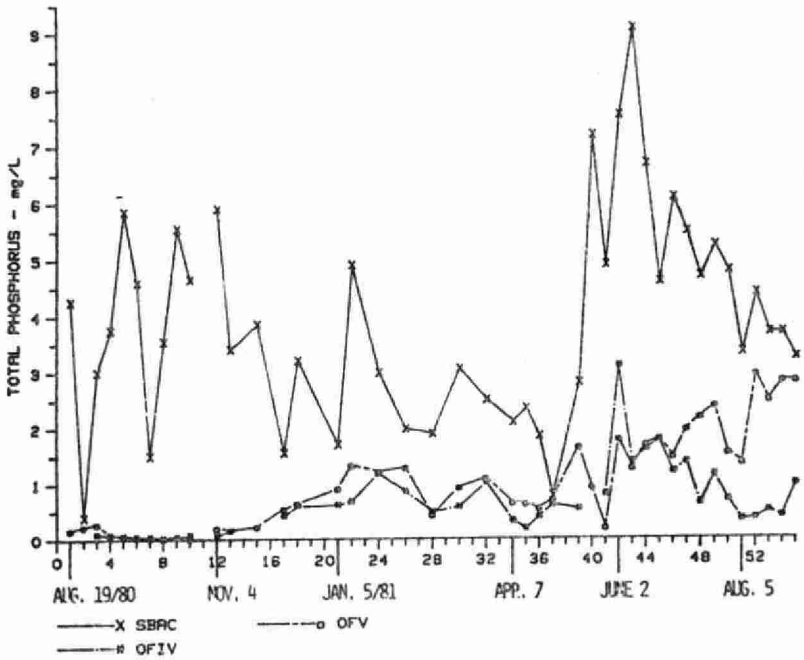


FIGURE 9 - SYSTEMS II AND III INFLUENT AND EFFLUENT TP CONCENTRATIONS

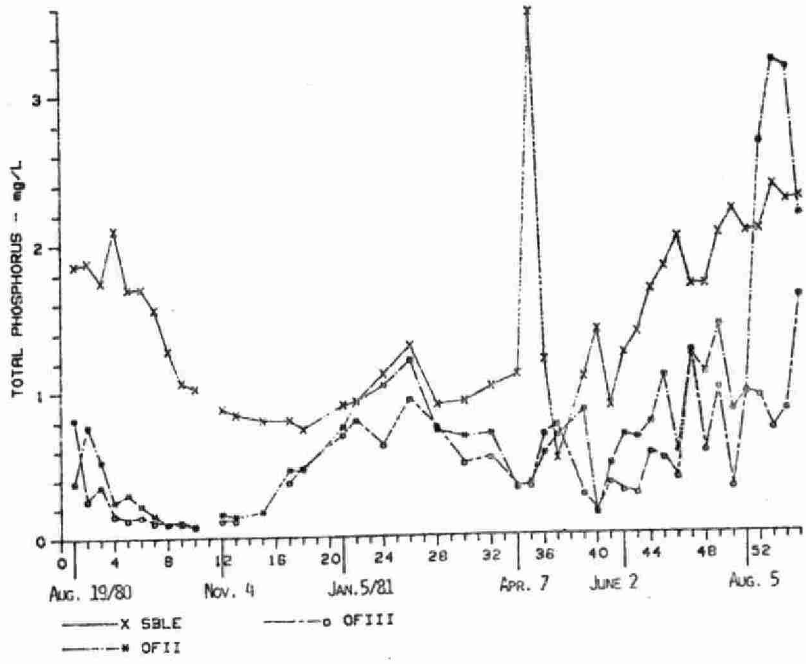


FIGURE 10 - INFLUENT AND EFFLUENT SRP CONCENTRATIONS OF SYSTEMS IV & V

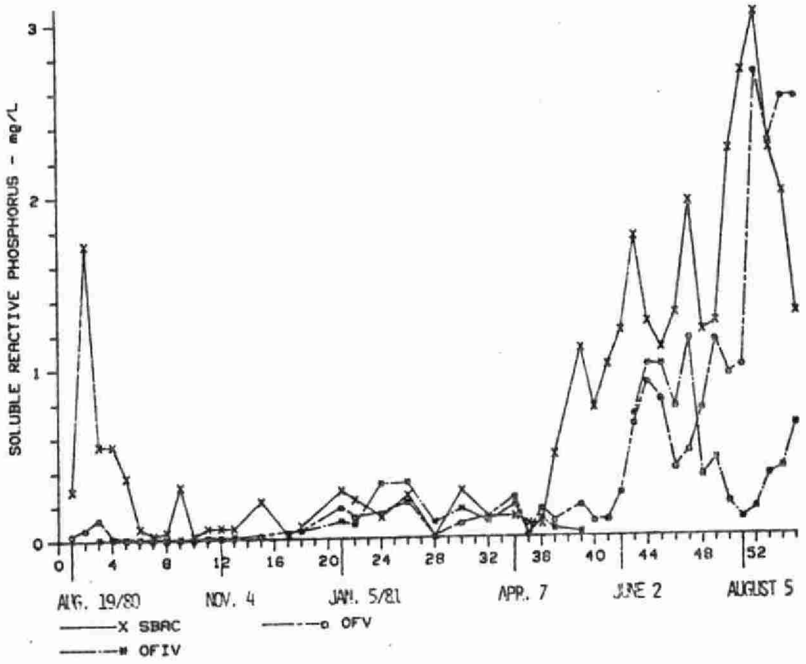


FIGURE 11 - INFLUENT & EFFLUENT SRP CONCENTRATIONS OF SYSTEMS II & III

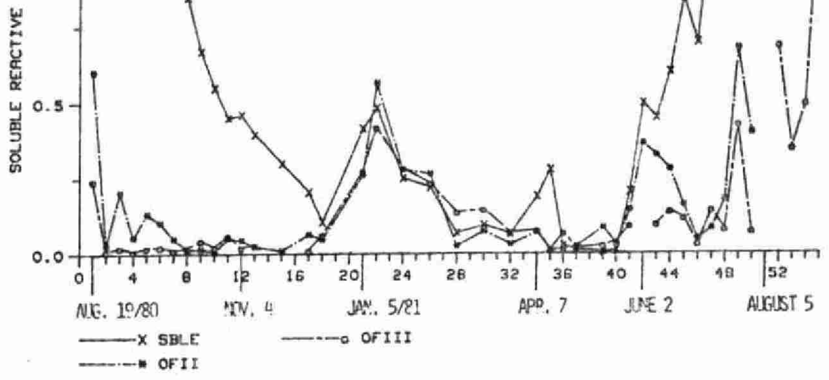


FIGURE 12 - PERCENT TP REMOVALS FOR SYSTEMS II TO V

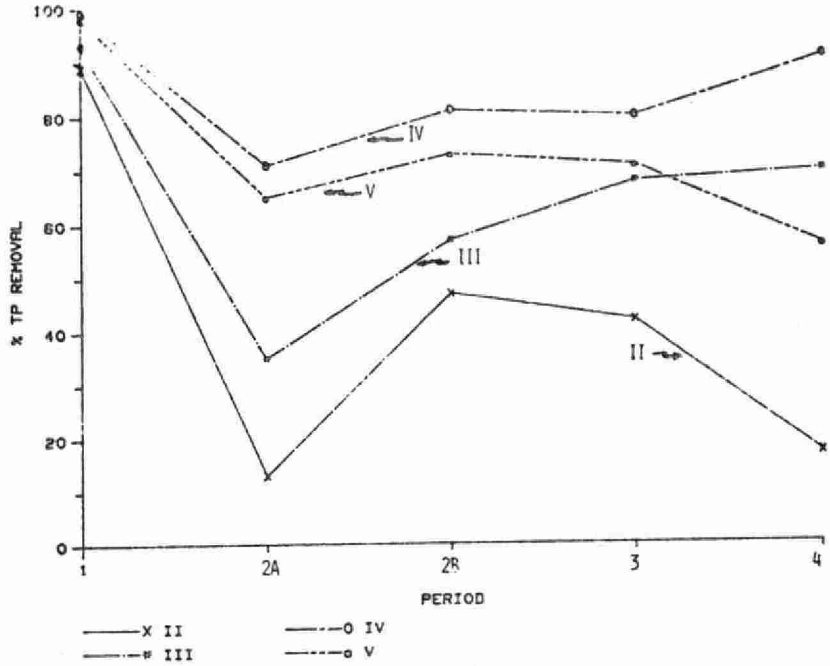


FIGURE 13 - PERCENT SRP REMOVALS FOR SYSTEMS II TO V

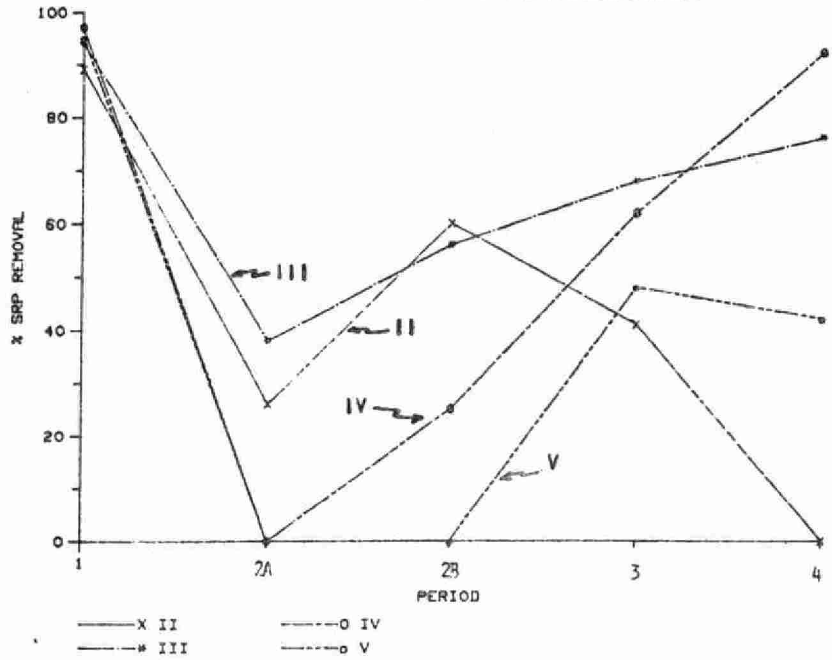


FIGURE 14 - SYSTEMS IV AND V INFLUENT AND EFFLUENT TN CONCENTRATIONS

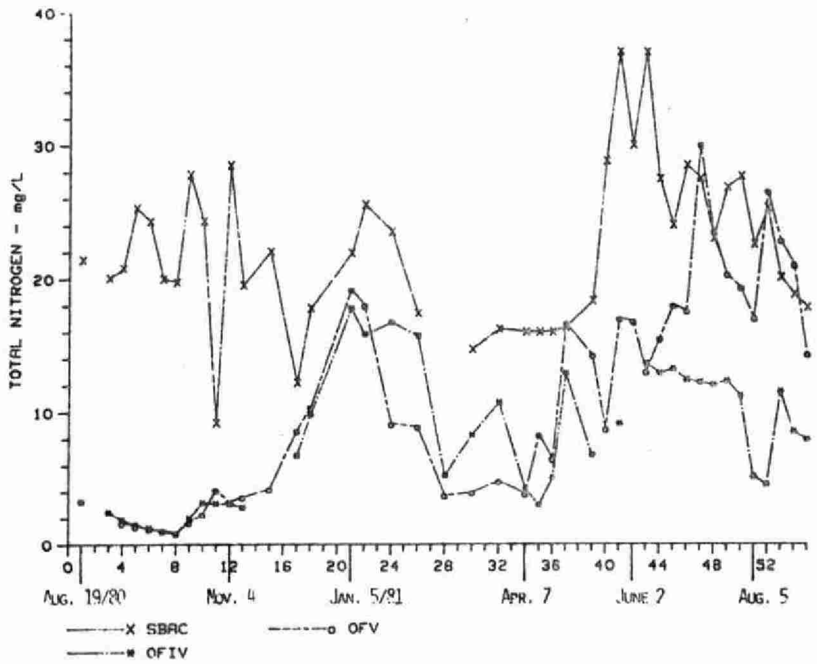


FIGURE 15 - SYSTEMS II AND III INFLUENT AND EFFLUENT TN CONCENTRATIONS

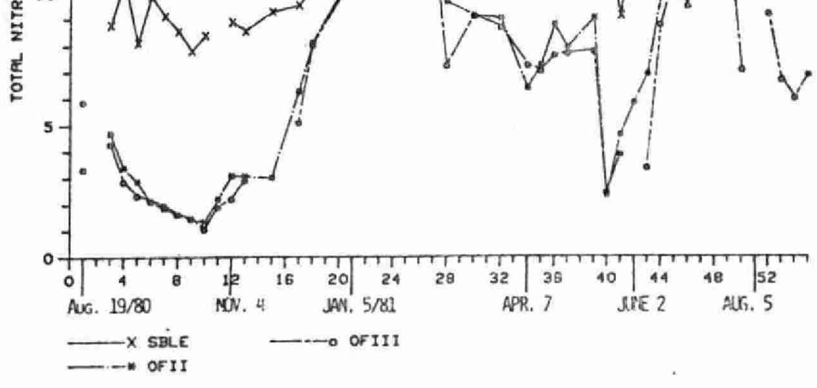


FIGURE 16 - PERCENT TN REMOVALS FOR SYSTEMS II TO V

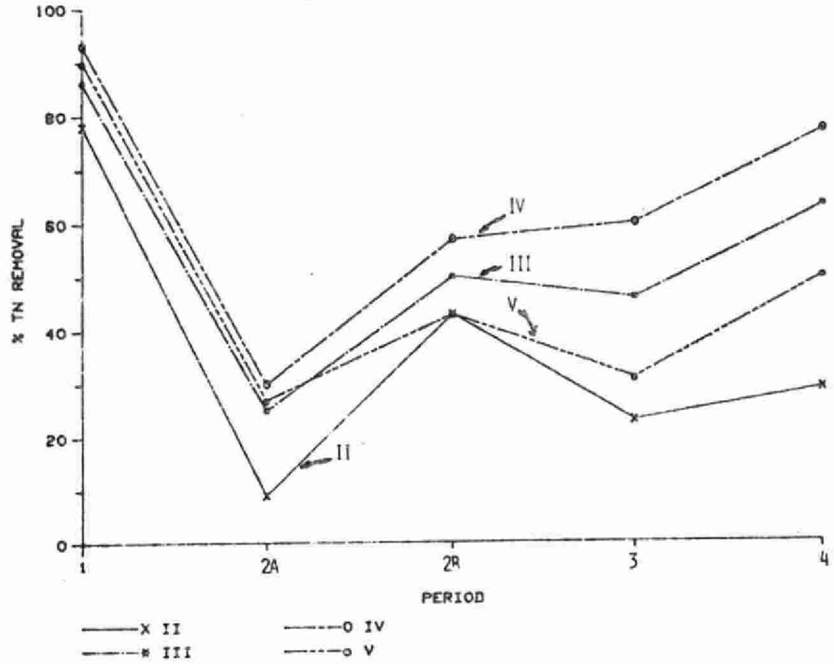
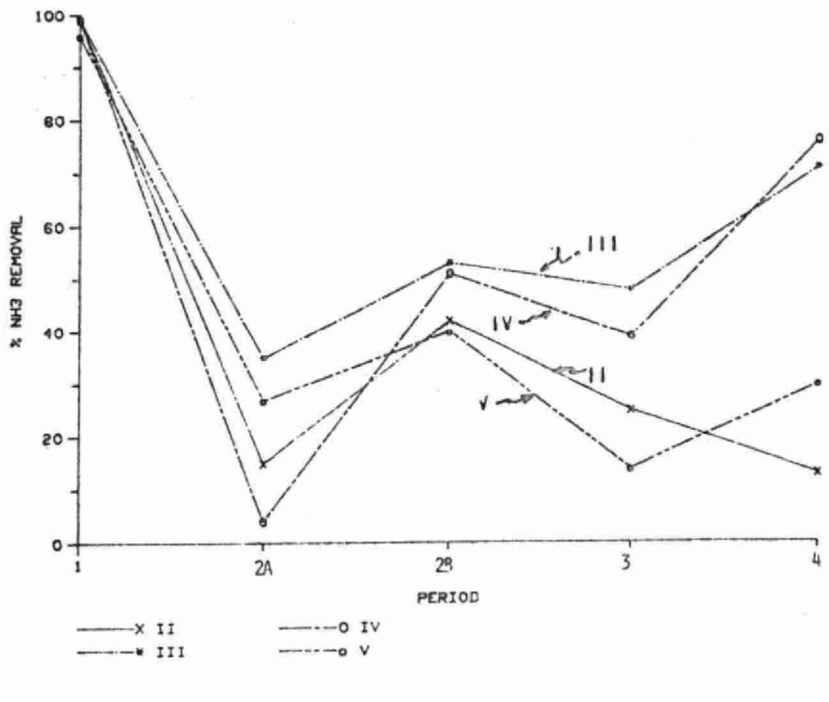


FIGURE 17 - PERCENT NH_3 REMOVALS FOR SYSTEMS II & V



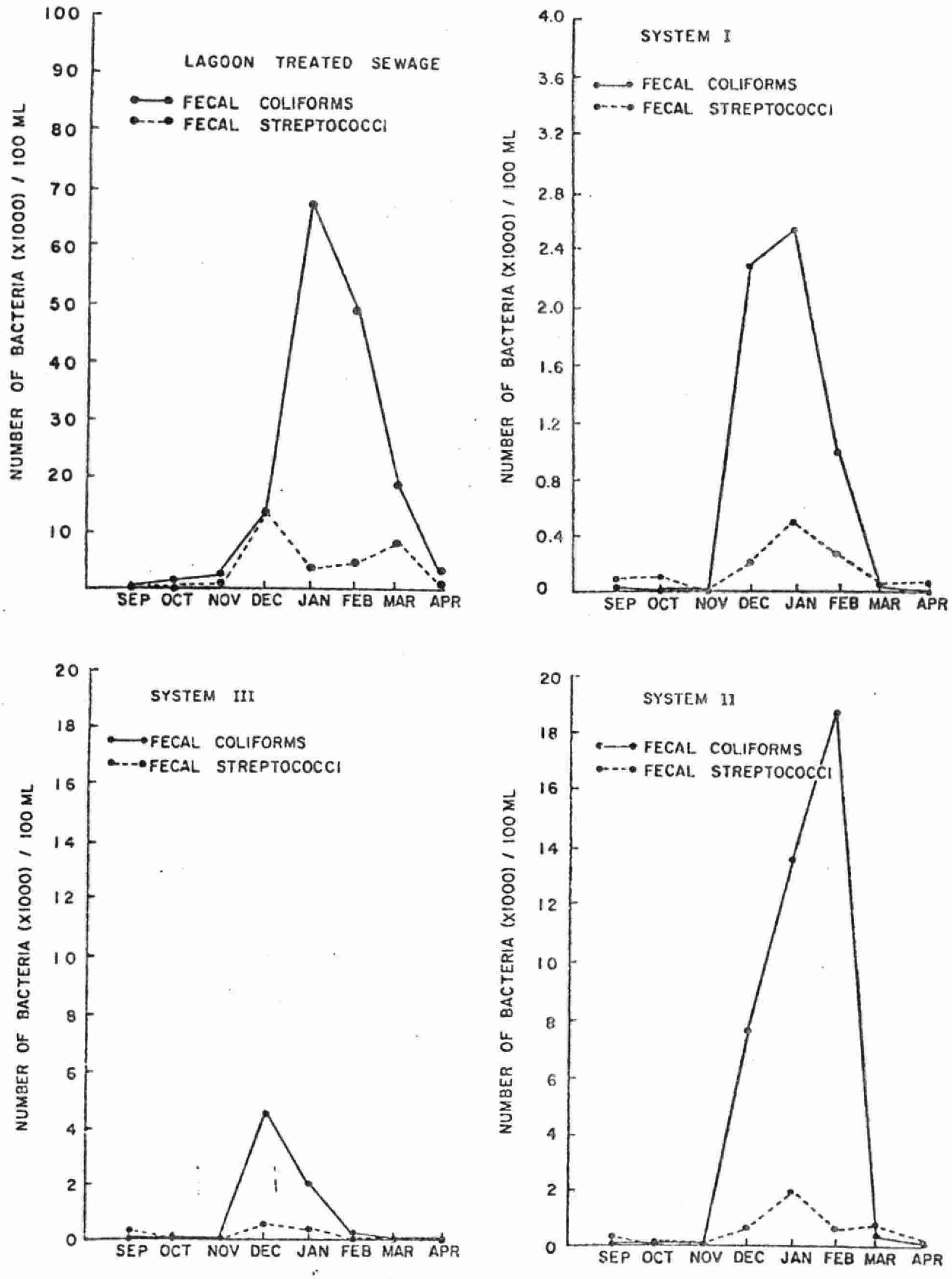


Figure 18. Bacterial populations in lagoon influent and systems I-III.

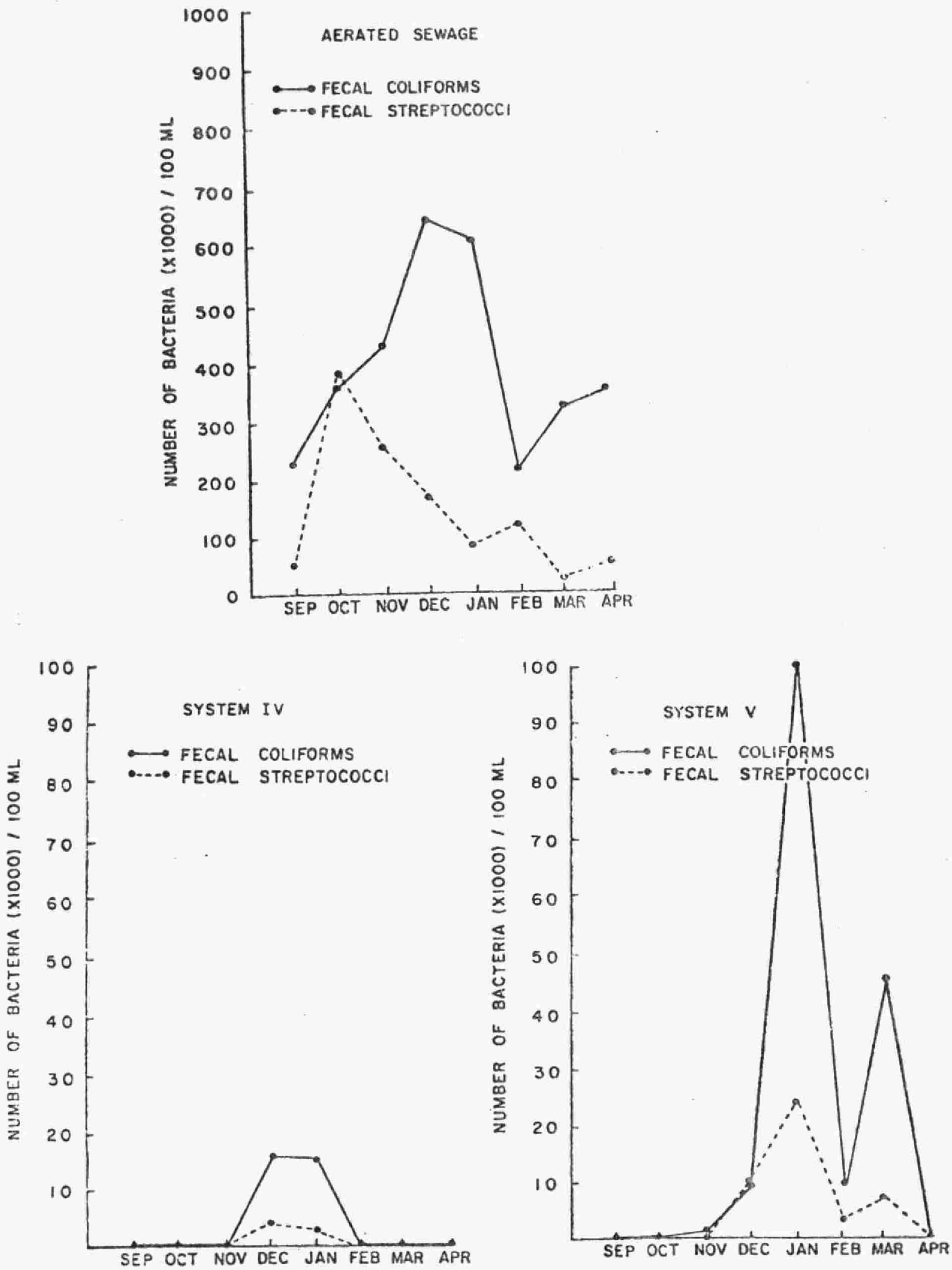


Figure 19: Bacterial populations in raw sewage influent and systems IV & V.